Crystal engineering of neutral *N*-arylpyrimidinones and their HCl and HNO_3 adducts with a C–H···O supramolecular synthon. Implications for non-linear optics

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In a previous crystallographic study of some *N*-arylpyrimidinones **1**, we noted that: (1) C–H···O hydrogen bonds connect molecules in a linear array; (2) the charge transfer axis of the chromophore is aligned with the main symmetry operator of point groups 2 or *m* at *ca.* 57°, a value that is close to the ideal angle of 54.74°; (3) the methyl and chloro derivatives are isostructural. In this paper, we report the characterisation of chloride and nitrate salt adducts of **1** by X-ray diffraction and the analysis of their packing motifs. Recurrence of the same C–H···O supramolecular synthon in three neutral and five HCl and HNO_3 adducts of **1** signifies the robustness of this weak hydrogen bond. The occurrence of a mirror plane *m* in a family of eight crystal structures (four *Pnma*, two $P2_1/m$, one *Pbcm*, and one $Pmn2_1$) is unusual because this symmetry operation is generally avoided due to close packing considerations. *Ab initio* calculations show that the bisected phenyl conformation present in these crystal structures is the most stable conformation of the pyrimidinone molecule. The presence of aryl and pyrimidinone chromophores in **1**, the correct alignment of the aromatic ring in the crystal and the occurrence of 2D polar layers in some crystal structures are favourable factors for non-linear optical applications. However, a strategy for the crystallisation of these achiral molecules in non-centrosymmetric space groups is yet to be achieved. This crystal engineering study simplifies the challenge of complete 3D structural control into a modular 2D + 1D problem.

Organic crystals have been intensely engineered in the last two decades for quadratic non-linear optics (NLO) because of potential applications in telecommunications, optical data storage and optical information processing.[1] The main challenge in NLO materials is to design crystals with a large quadratic susceptibility (χ^2), achieved by the optimal packing of polarisable molecules in a non-centrosymmetric fashion.[2] Both organic and inorganic materials have been engineered for second harmonic generation (SHG): POM (3-methyl-4-nitropyridine-1-oxide), NPP [*N*-(4-nitrophenyl)-(*S*)-prolinol], KDP [KH_2PO_4], $KTiOPO_4$, $LiNbO_3$ and $LiIO_3$. Strategies based on organic functional groups have the advantage that the molecular hyperpolarisability (β) can be increased through conjugated chromophores by tuning the donor/acceptor strength of the substituents and the length of the π-conjugated systems.[3] A classical approach for inducing non-centrosymmetry in organic crystals is the use of chiral centres grafted on organic templates by directed chemical synthesis.[4] But there is a need to find efficient strategies for better control of non-centrosymmetric packing with achiral molecules. Some recent approaches for inducing non-centrosymmetry in the bulk crystal that avoid the use of NLO chromophores in pure enantiomeric form are: (1) molecular octupoles with vanishing dipole moment;[5] (2) thermally stable salts of organic chromophores;[6] (3) donor–acceptor co-crystals;[7] (4) interpenetrated diamondoid networks;[8] and (5) the constrained channel of a perhydrotriphenylene host.[9] A unique feature of these recent approaches is that they utilise the enhanced knowledge of intermolecular interactions and hydrogen bonding in crystal engineering[10] and supramolecular chemistry[11] for the design of acentric crystals. The present study deals with the structural analysis of thermally stable ionic salts of a new organic chromophore.

We have recently examined the crystal structures of some 1,2-dihydro-*N*-aryl-4,6-dimethylpyrimidin-2-ones **1** (R = H, Me, Cl) with the idea of finding a new crystal engineering strategy to obtain acentric structures.[12] The introduction of NLO chromophores in such structures would be useful to get efficient SHG effects. These three crystal structures contain the same supramolecular synthon,[13] a chain of C–H···O hydrogen bonds[14,15] from the activated sp^2 C–H donor to the carbonyl O acceptor (2.1–2.3 Å, 170–180°). This linear arrangement of pyrimidinone molecules in the crystal is analogous to the α-network in urea derivatives[16](Fig. 1), with the weak C–H···O chain in the former structures replacing the strong N–H···O motif in the latter.[17] However, neutral pyrimidinones **1** are not of immediate SHG relevance because they adopt centrosymmetric packing (**1**H: *Pbcm*, **1**Me and **1**Cl: *Pnma*). Nonetheless, three factors about **1** are favourable from NLO considerations. The charge transfer axis of the aryl chromophore is oriented at an angle of *ca.* 57° to the C–H···O chain in the crystal, a value that is close to the optically ideal orientation of 54.74° in the

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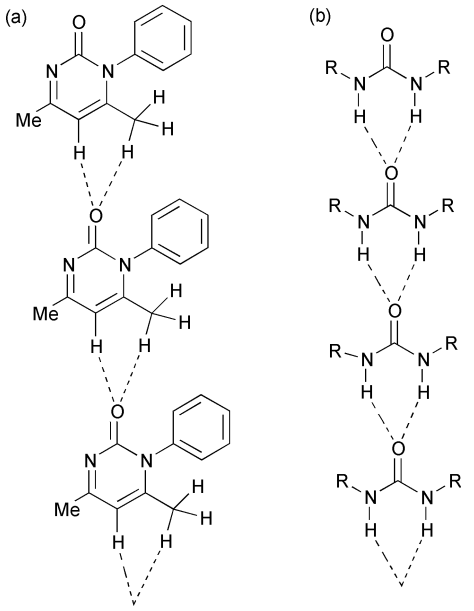
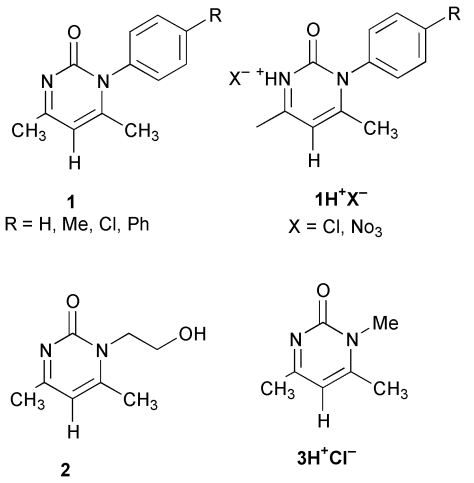


Fig. 1 (a) Linear chain of pyrimidinone molecules connected by the C–H···O synthon. (b) α-Network in urea. Note the topological identity between strong and weak hydrogen bonded synthons.



more frequent point groups 2, *m*, 222, *mm*2.[1c,2a] Secondly, *N*-hydroxyethylpyrimidinone **2** crystallises in the polar space group $P2_1$ through infinite chains of O–H···N hydrogen bonds.[18] Lastly, although crystal structures of **1** are centrosymmetric, the layers have a polar arrangement of molecules. A report on 2D lamellar polarity in some uronium sulfonate crystals[19] appeared in the literature while this manuscript was in preparation. In continuation of our studies on the novel heterocycle **1**, HCl and HNO_3 crystalline salt adducts were prepared and characterised by single crystal X-ray diffraction. In this paper, we analyse crystal structures of **1**H · HCl (*Pmn*2_1), **1**Me · HCl and **1**Cl · HCl (both $P2_1/m$), **1**Me · HNO_3 and **1**Cl · HNO_3 (both *Pnma*). These structures exhibit interesting behaviour from a crystal engineering viewpoint. The C–H···O chain supramolecular synthon (Fig. 1) is a recurring pattern[20] in the structures of three neutral (ref. 12) and five salt (this study) crystals. The occurrence of mirror symmetry in a family of structures, notwithstanding that space groups with mirror planes are generally not favoured,[21] is unprecedented to our knowledge. Isostructurality of the methyl and chloro crystal structures, namely chloro–methyl exchange,[22] is a result of synthon robustness. In order to assess the limit for the presence of crystallographic mirror symmetry, the crystal structure of 4-biphenylylpyrimidinone was determined. **1**Ph crystallises in the monoclinic space group $P2_1/a$. The absence of a visible SHG signal in the non-centrosymmetric crystals of **1**H · HCl is rationalised.

Experimental

Synthesis and characterisation

Synthesis of *N*-arylpyrimidin-2-ones 1. Acetylacetone (2.6 mL, 2.4 g, 24 mmol) and *N*phenylurea (2.7 g, 20 mmol) were taken up in 25 mL of dry ethanol and conc. HCl (5 mL) was added. The reaction mixture was refluxed for 3 h, cooled to room temperature and then in ice, filtered, and the solid washed with cold ethanol. The precipitated **1** · HCl salt (3.8 g) was dissolved in 10 mL water and neutralised with NaOH solution (0.7 g in 5 mL water) with ice-bath cooling. Extraction of the aqueous layer with chloroform and work-up gave the neutral phenylpyrimidinone **1**H (2.8 g). Similarly, other aryl derivatives were prepared.[12] Condensation with *para*-biphenylylurea[23] afforded crystals of **1**Ph. ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.75 (d, *J* 8 Hz, 2H), 7.60 (d, *J* 8 Hz, 2H), 7.50–7.20 (m, 3H), 7.25 (d, *J* 8 Hz, 2H), 6.20 (s, 1H), 2.39 (s, 3H), 2.00 (s, 3H). IR (KBr, cm^{-1}): 1640 (C=O group).

Preparation of salt adducts. Neutral **1** was dissolved in 10 mL of water in a beaker and conc. HCl or HNO_3 was added until the mixture became acidic. The solution was heated to a boil, filtered, concentrated and then left for crystallisation at ambient temperature. Diffraction quality crystals of **1** · HCl and **1** · HNO_3 were obtained after a few days.

Differential scanning calorimetry. DSC spectra were recorded on a Perkin Elmer instrument in the temperature range 30 to 240 °C at a rate of 20 °C min^{-1}.

Crystallography

Single crystal X-ray data on salt samples were collected on a Nonius-CAD4 diffractometer with Mo-Kα radiation ($\lambda = 0.7107$ Å) at ambient temperature. Data on 4-biphenylylpyrimidinone were collected on a Nonius-CCD Kappa diffractometer working with Ag-Kα radiation ($\lambda = 0.5608$ Å) from 180 exposures with $\Delta\phi$ scans, $\Delta\phi = 1°$, $2\theta_{max} = 35.2°$. No absorption corrections were applied. Hydrogen atoms of **1**H · HCl, **1**Me · HCl and **1**Cl · HCl were refined experimentally and H atoms in **1**Me · HNO_3, **1**Cl · HNO_3 and **1**Ph were fixed because of the limited number of reflections. Structures were solved using direct methods with the SIR92 program.[24a] Full-matrix least-squares refinements were performed on *F* using the teXsan software.[24b] Scattering factors for neutral atoms and f', $\Delta f'$, f'', $\Delta f''$ were taken from the *International Tables for X-ray Crystallography*.[24c] Details of crystal data collection, structure solution and refinement are listed in Table 1 and metrics of some important hydrogen bonds are summarised in Table 2. Crystal packing diagrams are drawn using PLATON.[24d]

CCDC reference numbers 171686–171691. See http://www.rsc.org/suppdata/nj/b1/b104646m/ for crystallographic data in CIF or other electronic format.

Cambridge structural database

The Cambridge Structural Database (April 2000 update, version 5.19, 215 403 entries)[25] was searched for crystal structures in the top three mirror-containing space groups, namely *Pnma*, $P2_1/m$ and $C2/m$,[26] in which a phenyl ring is bisected by a

Table 1 Crystal data and measurement details

	1H · HCl	**1**Me · HCl	**1**Cl · HCl	**1**Me · HNO_3	**1**Cl · HNO_3	**1**Ph
Chem. Form.	$C_{12}H_{13}N_2OCl$	$C_{13}H_{15}N_2OCl$	$C_{12}H_{12}N_2OCl_2$	$C_{13}H_{15}N_3O_4$	$C_{12}H_{12}N_3O_4Cl$	$C_{18}H_{16}N_2O$
Form. wt	236.70	250.73	271.15	277.28	297.70	276.34
T/K	296.2	296.2	296.2	296.2	296.2	296.2
Cryst. syst.	Orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Orthorhombic	Monoclinic
Space group	$Pmn2_1$	$P2_1/m$	$P2_1/m$	$Pnma$	$Pnma$	$P2_1/a$
a/Å	6.801(1)	7.304(1)	7.313(1)	26.559(3)	26.880(3)	12.602(2)
b/Å	12.199(1)	6.767(1)	6.668(2)	6.373(1)	6.348(1)	10.201(3)
c/Å	7.327(1)	13.444(2)	13.644(2)	8.079(1)	8.102(1)	23.118(6)
α/°	90	90	90	90	90	90
β/°	90	105.59(1)	105.23(1)	90	90	94.37(2)
γ/°	90	90	90	90	90	90
U/Å^3	607.9(1)	640.1(1)	641.9(2)	1367.4(1)	1382.5(3)	2963(1)
Z	2	2	2	4	4	8
μ/mm^{-1}	0.294	0.284	0.489	0.102	0.292	0.050
N(total)	2150	4953	8137	4314	4354	6240
N(indep.)	1654	2569	4195	2333	2694	3673
N(used)	1105	1448	1726	758	759	850
$I > 2.5\sigma_I$	$I > 3\sigma_I$	$I > 3\sigma_I$	$I > 3\sigma_I$	$I > 3\sigma_I$	$I > 3\sigma_I$	
R_{int}	0.014	0.022	0.028	0.035	0.066	0.095
R_1	0.039	0.037	0.038	0.061	0.059	0.074
R_w	0.052	0.043	0.041	0.066	0.063	0.078

Table 2 Geometry of intermolecular interactions

Compound	Interaction[a] D–H···A	H···A/Å	D···A/Å	D–H···A/°
1H · HCl[b]	C3–H4···O1 (i)	2.77(4)	3.555(3)	146(3)
	C5–H5 · O1 (ii)	2.31(6)	3.216(4)	169(4)
	N2–H1 · Cl1 (iii)	2.01(6)	3.029(2)	158(4)
	C10–H9 · Cl1 (iv)	3.03(4)	3.961(3)	168(4)
	C8–H7···Cl1 (v)	2.68(3)	3.595(2)	146(2)
	C6–H1···O1 (vi)	2.75(5)	3.429(1)	136(2)
1Me · HCl[b]	C3–H1···O1 (i)	2.75(2)	3.547(3)	146(2)
	C5–H2···O1 (ii)	2.39(3)	3.221(3)	170(2)
	N2-H10···Cl1 (iii)	2.15(3)	3.030(2)	176(2)
1Cl · HCl[b]	C3–H4···O1 (i)	2.82(2)	3.560(2)	140(1)
	C6–H5···O1 (ii)	2.34(3)	3.217(3)	165(2)
	N1-H1···Cl2 (iii)	2.11(3)	3.010(2)	177(2)
1Me · HNO_3[c]	C5–H2···O1 (i)	2.59	3.389(7)	142
	N2–H10···O4 (ii)	1.89	2.845(5)	166
	C3–H1···O4 (iii)	2.38	3.500(6)	172
	C6–H4···O2 (iv)	2.22	3.173(7)	177
1Cl · HNO_3[c]	C5–H3···O1 (i)	2.61	3.419(10)	143
	N2–H1···O3 (ii)	1.90	2.812(7)	163
	C3–H2···O3 (iii)	2.54	3.489(9)	174
	C6–H5···O2 (iv)	2.15	3.080(9)	174
3 · HCl[d]	C7–H13···O2 (i)	2.63(2)	3.405(2)	146(2)
	C10–H11···O2 (ii)	2.65(3)	3.446(3)	161(2)
	N4-H12···Cl1 (iii)	2.13(2)	3.034(1)	175(2)
1Ph(neutral)[c]	C3–H1···O1 (i)	2.19	3.20(2)	155
	C5–H4···O1 (ii)	2.64	3.58(1)	145
	C21–H17···O2 (iii)	2.21	3.24(2)	155

[a] The Roman numbers after each interaction refer to the figures. [b] H atom refined experimentally. [c] H atom rides on the C/N carrier. [d] Ref. 32.

Table 3 CSD refcodes of organic structures in which a phenyl ring is bisected by a mirror plane in three common space groups

Pnma	$P2_1/m$	$C2/m$
HALKUA	JIFLIW	DADYAI
MEACAN10	KANCAD	KOSBUP
REKJUM	LINBIT	PERWUE
REKKEX	PIJXEL01	QAFXOK
RUHQOA	PMIQLO	SEQYIW
TUFQOA	TIQDIG	
YAZZOO	YILZUO	
YIZHEU	ZOMDIO	

mirror plane. This was done manually from the sub-set of organic structures (screen 57) that contain a phenyl ring in these three space groups. The list of refcodes is given in Table 3.

Results and discussion

Pyrimidinones **1** were synthesised as described previously.[12] Recrystallisation of **1** from an aqueous solution of HCl or HNO_3 furnished the corresponding *N*-protonated salts as diffraction quality crystals. Reflections were collected on crystals of **1**H · HNO_3 but the data could not be solved and

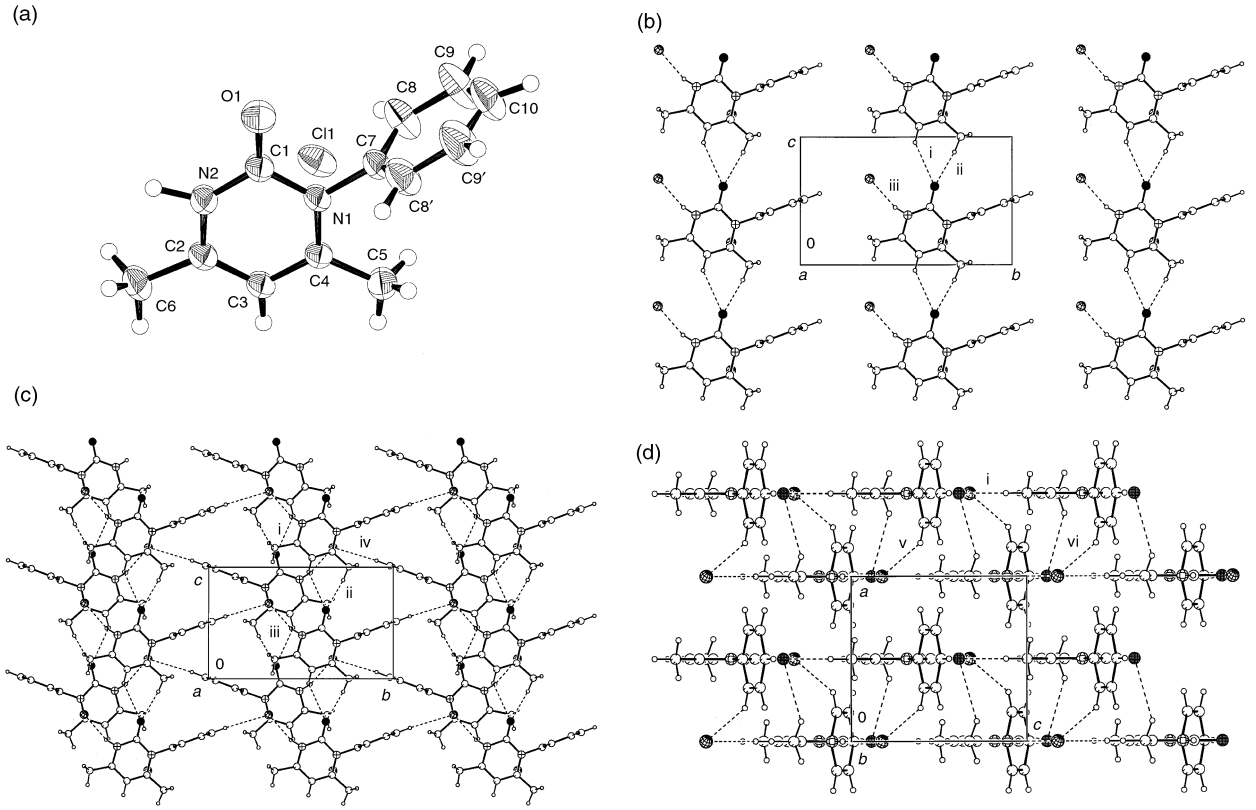


Fig. 2 (a) ORTEP plot of **1**H · HCl showing the bisected phenyl conformation in the molecule. Thermal ellipsoids are drawn at the 50% probability level for non-H atoms in this and subsequent diagrams. (b) Linear array of phenylpyrimidinone molecules in the crystal structure of **1**H · HCl mediated by the V-shaped C–H···O synthon. (c) N^+–H···Cl^-, C–H···O and C–H···Cl^- hydrogen bonds stabilise the *bc* layer. Note the parallel stacking of 2D polar layers. (d) Side view showing the stacking of layers. See Table 2 for the description of the weak interactions.

refined because of heavy distortions of the phenyl ring. Crystal structures of the chloride and nitrate salts of **1**Me and **1**Cl are discussed together because these pairs have identical packing features. Crystals of neutral 4-biphenylylpyrimidinone **1**Ph were obtained from ethyl acetate.

C–H···O synthon in crystal packing

1H · HCl crystallises in the space group $Pmn2_1$. The heterocyclic pyrimidinone ring lies on the mirror plane; the *N*-phenyl ring is orthogonal and bisected [Fig. 2(a)]. A bifurcated motif of C–H···O hydrogen bonds from vinyl and methyl donors (2.77 Å, 146°; 2.31 Å, 169°; Table 2) connect translation-related molecules along [001] [Fig. 2(b)]. Such chains are cross-linked via N^+–H···Cl^- (2.01 Å, 158°) and C–H···Cl^- (3.03 Å, 168°) hydrogen bonds to produce a lamellar motif in the (100) plane [Fig. 2(c)]. The polar layers of phenylpyrimidinone molecules pack in a non-centrosymmetric fashion such that the phenyl ring projects out of the *bc* plane above and below the pyrimidinone ring of adjacent 2_1 related molecules [Fig. 2(d)]. The inter-layer region is stabilised by a combination of C–H···O, C–H···Cl^- and van der Waals interactions (2.6–2.8 Å). All in all, weak hydrogen bonds[14] play a crucial role in aggregating molecules in the crystal structure of **1**H · HCl. Concerning hydrogen bonds with a Cl atom as the acceptor, it was shown in a recent database study[27] that metal-bound chlorine and chloride ions accept hydrogen bonds from O–H and N–H donors. The N^+–H···Cl^- hydrogen bond at 2.01 Å is in the short distance range of the H···Cl^- histogram.[27] C–H···Cl^- hydrogen bonds too have been analysed using the database approach.[28]

1H · HCl is the only pyrimidinone adduct that has a non-centrosymmetric crystal structure in the present series studied. When a crystalline sample of this material was subjected to the Kurtz and Perry[29] SHG powder test with laser light at 1.06 μm, no visible second harmonic signal was detected at 530 nm. In a control experiment, crystalline urea showed a highly visible green light under identical laser conditions. Examination of the crystal structure of **1**H · HCl offers an explanation for the absence of a visible SHG signal. Although the phenyl ring is oriented correctly in the acentric crystal for phase matching, the chromophore bears no electron-withdrawing/donating functional groups to extend the π-conjugation. Moreover, since the phenyl and pyrimidinone rings are orthogonal, there is no possibility of intramolecular charge transfer leading to a significant hyperpolarisability. The pyrimidinone ring itself is a modestly polarisable chromophore, but the SHG effect is probably too feeble to be visible to the human eye.

1Me · HCl and **1**Cl · HCl are isostructural ($P2_1/m$) with very similar cell dimensions [Fig. 3(a) and 3(b); Table 1]. In **1**Me · HCl a V-shaped C–H···O synthon (2.75 Å, 146°, 2.39 Å, 170°) and N^+–H···Cl^- hydrogen bond (2.15 Å, 176°; Table 2) connect pyrimidinone molecules in the mirror plane. Although the pyrimidinone rings of **1** are aligned parallel in the *ac* layer with their carbonyl groups pointing in the same direction (2D polarity) as shown in Fig. 3(c), the structure is centrosymmetric because adjacent layers are inversion-related [Fig. 3(d)]. C–H···O interactions (2.6–2.7 Å) stabilise the inter-layer region. Isostructurality of methyl- and chloro-pyrimidinone crystals in neutral[12] and salt structures is attributed to the robust C–H···O synthon. These pyrimidinone derivatives show chloro–methyl exchange[22] because these two groups with similar volumes (Cl 20 $Å^3$, Me 24 $Å^3$) play a space-filling role in the crystal. Notice that the tolyl groups in Fig. 3(d) can be replaced by chlorophenyl without any change in the rest of the crystal structure. There are no short Cl···Cl interactions[30] (up to 4 Å) in **1**Cl · HCl. It was shown recently in the context of

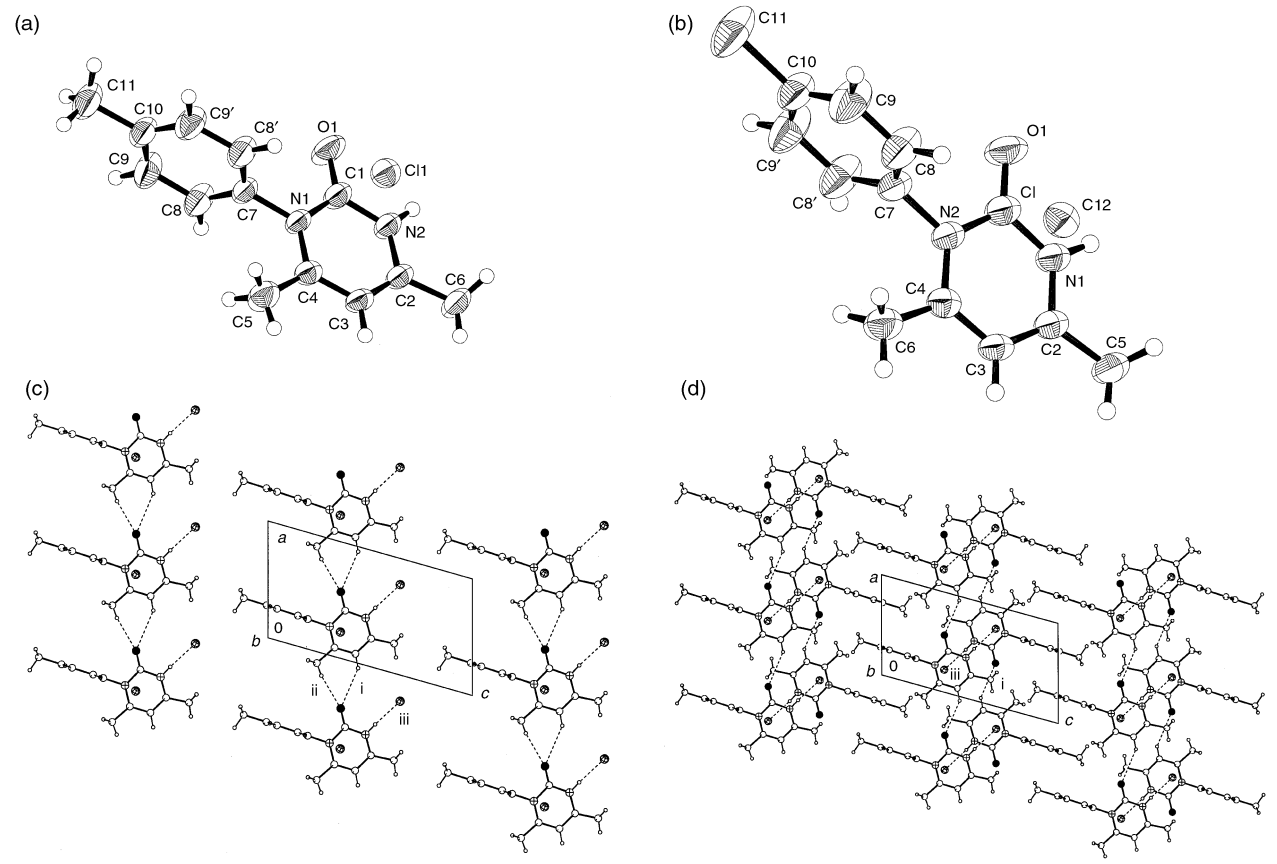


Fig. 3 ORTEP plots of (a) **1**Me · HCl and (b) **1**Cl · HCl showing the bisected phenyl conformation. (c) Lamellar packing of tolylpyrimidinone molecules in **1**Me · HCl stabilised by V-shaped C–H···O synthon and N^+–H···Cl^- hydrogen bond. Note the 2D polar arrangement. (d) Interlayer region in **1**Me · HCl stabilised by N^+–H···Cl^- and C–H···O hydrogen bonds. The space group, cell dimensions and crystal packing in **1**Cl · HCl are very similar. See Table 2 for the description of the weak interactions.

CH_3 and CF_3 exchange[31] that crystal structures with robust supramolecular synthons are able to tolerate up to a three fold increase in volume (vdW hemisphere: CH_3 17 Å^3, CF_3 43 Å^3) without perturbing the overall organisation in the lattice. The 30% void space in molecular crystals can accommodate such structural adjustments.

The nitrate salts, **1**Me · HNO_3 and **1**Cl · HNO_3, are isostructural [Fig. 4(a) and 4(b)] and have the same space group as the neutral molecules (*Pnma*). However, the arrangement of molecules in the neutral and adduct structures is quite different. While pyrimidinone molecules in the *ac* layer point in the same direction [Fig. 4(c)] in neutral **1**Me and **1**Cl (2D polarity),[12] the layers are centrosymmetric in the nitrate adducts [Fig. 4(d)]. The C–H···O chain in **1**Cl · HNO_3 (2.61 Å, 143°) originates from the methyl hydrogen donor and the acceptor is not bifurcated as observed in the chloride salt structures. NO_3^- ions connect molecules along [001] through an intricate network of N–H···O (1.90 Å, 163°) and C–H···O hydrogen bonds (2.54 Å, 174°, 2.15 Å, 174°, Table 2). Aryl rings of inversion-related molecules are interdigitated between hydrogen-bonded domains [Fig. 4(d)].

Mirror symmetry: CSD analysis and RHF computations

The presence of molecules on a mirror plane in crystal structures is generally avoided because it decreases packing efficiency by 0.02–0.03. However, retention of *m* or 2 symmetry in crystals is thermodynamically advantageous because the molecules are symmetrically arranged.[21] In space groups with a mirror plane, the molecules *must* reside on the special position: otherwise, the structure is usually disordered. In this sense, crystalline derivatives of **1** follow the rule: the pyrimidinone ring resides on the mirror plane ($Z' = 0.5$); the *N*-phenyl ring is orthogonal and bisected. Given that *m* symmetry is not common in crystals, the recurrence of a mirror plane in pyrimidinone crystal structures was examined further.

A closely related molecule, *N*-methylpyrimidinone hydrochloride **3** (CSD refcode COBYIB),[32] crystallises in space group $P2_1/n$. Interestingly, this crystal structure has a layer motif like the chloride adducts of **1** but without a mirror plane (Fig. 5, Table 2). The absence of mirror symmetry in **3** despite its resemblance to *N*-arylpyrimidinones **1** led us to carry out an analysis of crystal structures in the CSD that have a phenyl group and are bisected by a mirror plane. This exercise was carried out for the top three mirror-containing space groups,[26] *Pnma*, $P2_1/m$ and $C2/m$(Table 3). While there are examples of phenyl rings being bisected by a mirror plane in crystal structures, these are special cases with specific reason(s) determining the packing in each structure. A manual examination of the refcodes in Table 3 shows that there is no precedence for the occurrence of mirror symmetry in a family of structures.

Since crystallographic analysis did not provide a satisfactory explanation, it was felt that there could be a molecular feature in pyrimidinone **1** that favours a bisected phenyl ring conformation. The RHF (restricted Hartree–Fock) energy of neutral **1**H was calculated in the PC Spartan Pro 1.0 program[33] with STO-3G, 3-21G* and 6-31G* basis sets. The energy of the molecule (E/au) and torsion angle about the pyrimidinone–phenyl (O)C–N–C–C(Ph) bond (τ/°) are listed in Table 4. In the minimum energy conformation of **1**H calculated using 3-21G* and 6-31G*, the phenyl ring is orthogonal to the pyrimidinone heterocycle. The energy profile of **1**H as a function of phenyl group torsion about the N–C bond was calculated in the range 0 to 180° with 3-21G* (Fig. 6). This basis set was selected because it gives a comparable result to 6-

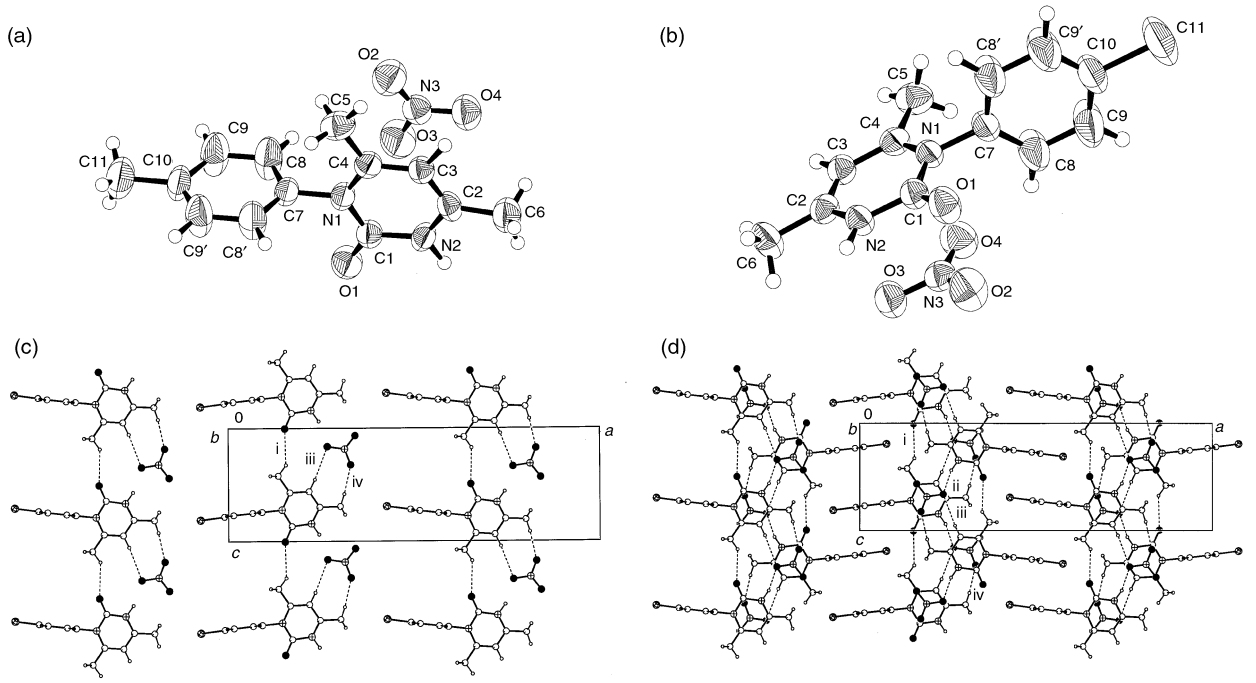


Fig. 4 ORTEP plots of (a) $\mathbf{1}Me \cdot HNO_3$ and (b) $\mathbf{1}Cl \cdot HNO_3$. The pyrimidinone ring and the nitrate ion occupy the mirror plane and the phenyl ring is bisected. (c) Lamellar packing of $\mathbf{1}Cl \cdot HNO_3$ molecules with C–H···O hydrogen bonds along [001]. Note that the molecules are aligned anti-parallel within the *ac* layer. (d) N^+–H···O^- and C–H···O hydrogen bonds in the intra- and inter-layer region of $\mathbf{1}Cl \cdot HNO_3$ and the inter-digitation of aryl groups between hydrogen bonded columns. $\mathbf{1}Me \cdot HNO_3$ is isostructural to the chloro derivative. See Table 2 for the description of the weak interactions.

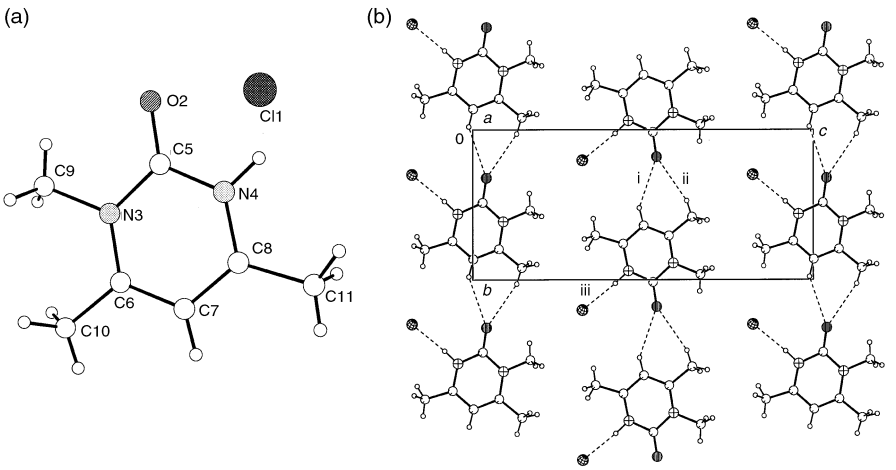


Fig. 5 Crystal packing in $\mathbf{3} \cdot HCl$ (refcode COBYIB). (a) Numbering scheme. (b) Notice the presence of the V-shaped C–H···O synthon and N^+–H···Cl^- hydrogen bond in this structure. See Table 2 for the description of the weak interactions.

31G* with about a three-fold saving of computer time. The bisected conformation of **1**H ($\tau = 90°$) is 0.030 au (18 kcal mol^{-1}; 1 au = 627 kcal) more stable than the almost planar conformation ($\tau = 2$, 178°). The energy of the perfectly planar conformation ($\tau = 0$, 180°) could not be calculated in the Profile run, presumably because the energy of the all-planar

Table 4 RHF energy of *N*-phenylpyrimidinone **1**H calculated in PC Spartan Pro

	E/au	E/kcal mol^{-1}	τ/°
STO-3G	−637.143	−399807.23	77.21
321-G*	−641.580	−402591.45	90.08
631-G*	−645.186	−404854.22	89.67

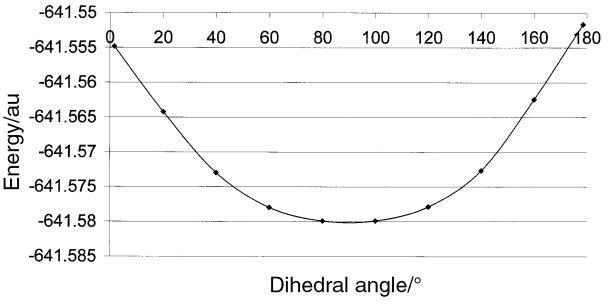


Fig. 6 RHF 3-21G* energy *vs.* (O)C–N–C–C(Ph) torsion angle in phenylpyrimidinone **1**H calculated using Spartan Pro 1.0 on a Pentium PC.

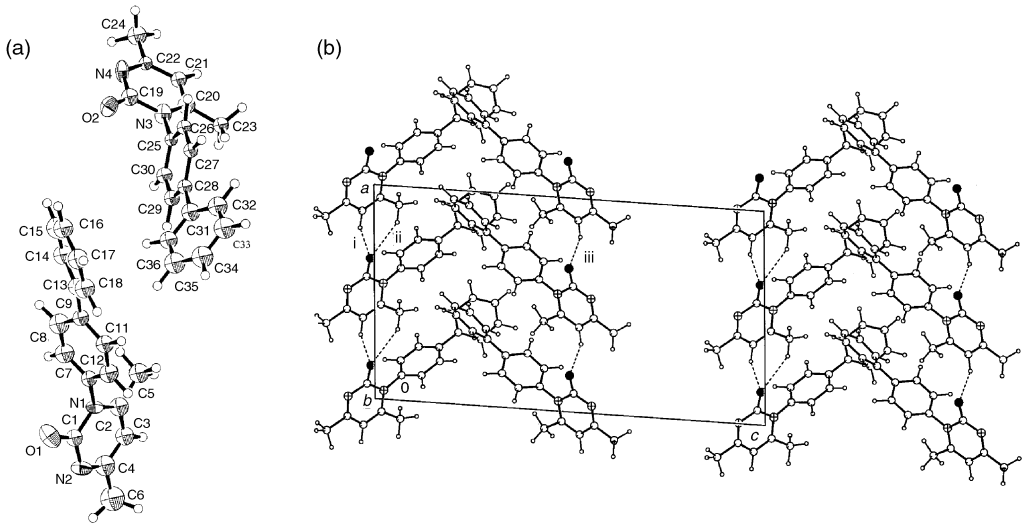


Fig. 7 (a) ORTEP plot of biphenylylpyrimidinone **1**Ph. There are two symmetry-independent molecules in the crystal. (b) Glide-related molecules are connected by V-shaped and linear chain C–H···O synthons. Phenyl rings of symmetry-independent molecules are stabilised by the herringbone T-motif. Inversion-related molecules are not shown for clarity. See Table 2 for the description of the weak interactions.

conformation is so high that the program starts about 2° away from the extreme values. Thus, RHF calculations explain the recurrence of mirror symmetry in *N*-arylpyrimidinones: intermolecular interactions and close packing are optimised in the crystal with the molecule adopting the stable bisected-phenyl conformation.

4-Biphenylylpyrimidinone

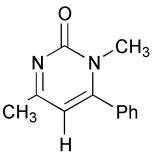
In addition to energy calculations, we felt that the crystal packing of 4-biphenylylpyrimidinone would clarify matters. The biphenyl analogue **1**Ph was synthesised by condensation of 4-biphenylylurea[23] with acetylacetone. In *Pbcm*, *Pnma* or $P2_1/m$ space groups observed in this family, the pyrimidinone ring of **1**Ph will occupy the mirror plane and the *N*-phenyl moiety will be orthogonal. The *para*-phenyl ring can be either (1) coplanar with the *N*-phenyl ring, or (2) orthogonal to the *N*-phenyl ring, or (3) oriented at some arbitrary angle but disordered to conform to the crystallographic mirror symmetry. Alternatively, the structure may adopt other common space groups like $P2_1/c$, *Pbca* or *P*1. In any event, this result will shed light on the interplay of forces that control the recurrence of mirror symmetry. Option (1) causes steric crowding of phenyl rings in the same plane while in (2) the steric penalty is released but there is break down of conjugation in the biphenyl chromophore.

The neutral molecule **1**Ph crystallises in the $P2_1/a$ space group with two molecules [Fig. 7(a)] in the asymmetric unit ($Z' = 2$). The *N*-phenyl group is twisted by an angle of 84.8, 87.9° at the N–C bond with respect to the pyrimidinone ring and the *para*-phenyl group is twisted by 145.3, 152.5° about the C–C bond. Significantly, the biphenyl group in both molecules is ordered. Crystallographically independent molecules are present in distinct chains. Glide-related molecules are connected by a V-motif (2.19 Å, 155°, 2.64 Å, 145°) and a linear chain (2.21 Å, 155°) of C–H···O interactions [Fig. 7(b)]. Interestingly, the C–H···O synthon is preserved in **1**Ph despite the loss of mirror symmetry in the crystal and the increase of Z' from 0.5 to 2. In the hydrophobic region between hydrogen bonded synthons, aryl groups of symmetry-independent molecules interdigitate *via* the herringbone T-motif.

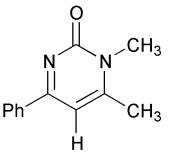
To summarise, two structural types are present in the pyrimidinone family. *N*-Arylpyrimidinones (R = H, Me, Cl) have *m* symmetry in their crystal structures while *N*-methyl and *N*-biphenylylpyrimidinones have a 2_1 screw axis. Yet, chemical recognition is mediated by the robust C–H···O synthon, a recurring pattern in all these structures. It is possible that the recurrence of mirror symmetry is an artefact of crystal data being collected at room temperature.[34] Further experimentation is necessary to answer questions such as: (1) Will crystal data collected on *N*-arylpyrimidinones at low temperature solve in space groups without a mirror plane? (2) Will data on the *N*-biphenylyl derivative collected at high temperature solve in a mirror symmetry setting? In this context, DSC spectra were recorded on neutral molecules and salt adducts of **1**.[35] **1**H, **1**Me, **1**Cl and **1**Ph show a sharp endotherm at the melting temperature. The chloride salts, **1**H · HCl, **1**Me · HCl and **1**Cl · HCl, do not exhibit a phase transition up to 240 °C. The nitrate salts, **1**Me · HNO_3 and **1**Cl · HNO_3, decompose between 170–190 °C as indicated by the sharp exotherm.

Conclusions

We set out to study the alignment of the aryl chromophore in a new family of *N*-heterocycles. Crystal structures of four neutral molecules and five crystalline salts have been determined and their packing characteristics analysed. The recurrence of the C–H···O synthon in *N*-arylpyrimidinones opens up the possibility of crystal engineering with a novel molecular scaffold in which functional groups can be manipulated to tailor the target architecture. Pyrimidinone derivatives **4a** and **4b** should be interesting candidates for further study because extended conjugation of the phenyl ring with the heterocycle will increase the molecular hyperpolarisability. The occurrence of a crystallographic mirror plane in *N*-arylpyrimidinones is explained through *ab initio* computations as the tendency of the molecule to adopt the lowest energy conformation in the crystal. A possible reason for the ordered arrangement of molecules in the solid state, notwithstanding that structures with mirror planes tend to be disordered, could be the intricate network of weak interactions, namely C–H···O, C–H···N, C–H···Cl^- and the herringbone motif.



4a



4b

Of the nine pyrimidinone crystal structures analysed, five structures have a 2D polar layer arrangement, **1**Me, **1**Cl, **1**Me · HCl, **1**Cl · HCl, **1**Ph, and one structure, **1**H · HCl, is 3D non-centrosymmetric. The recurring C–H···O synthon and the occurrence of 2D polarity in these structures simplifies the task of directing self-assembly for useful crystal properties to the third dimension. Studies are currently ongoing to optimise the aromatic chromophore and induce crystallisation of pyrimidinone adducts in non-centric space groups.

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